The use of Planetary Nebulae precursors in the study of Diffuse Interstellar Bands

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Abstract. We present the first results of a systematic search for Diffuse Interstellar Bands in a carefully selected sample of post-AGB stars observed with high resolution optical spectroscopy. These stars are shown to be ideal targets to study this old, intriguing astrophysical problem. Our results suggest that the carrier(s) of these bands may not be present in the circumstellar environments of these evolved stars. The implications of the results obtained on the identification of the still unknown carrier(s) are discussed.

INTRODUCTION

Diffuse Interstellar Bands (DIBs, hereafter) are bands of variable strength and width of still unknown origin which appear overimposed on the spectra of bright but heavily reddened stars. Since their discovery, now more than 80 years ago, they have been associated to the interstellar medium, because their strength appear to be well correlated with the observed extinction.

Currently, nearly 300 DIBs are catalogued (Galazutdinov et al. 2000) extending from ultraviolet to near-infrared wavelengths (3600–12000 Å), the most studied ones being those found at 4430 Å, 5780 Å, 5797 Å and 6284 Å.

Many carriers have been proposed, but for none of them convincing arguments exist so far (for a review see Fulara & Krelowski 2000). The problem still constitutes a major challenge for spectroscopists, astronomers and physicists.

The suspicion is that the carrier(s) may have a molecular nature, as substructures ressembling the PQR-branches of ro-vibrational transitions have been detected in some of these bands, when observed with very high spectral resolution (Kerr et al. 1998).

On the other hand, the existence of *families* of DIBs (Krelowski & Walker 1987) suggests that there is not a unique carrier. Moreover, the species implicated must be ubiquitous in space, since DIBs have been detected towards a wide variety of astronomical sources, from comets to external galaxies.

The most promising hypothesis are: (i) long carbon chains, like polyacetylenes (Douglas 1977); (ii) PAH cations (Allamandola et al. 1999; Salama et al. 1999); or (iii) fullerenes (Foing & Ehrenfreund 1994).

There are strong evidences that the relative strength of DIBs are correlated with the properties of the clouds in the line of sight. This environmental dependence may reflect an interplay of ionization, recombination, dehydrogenation and destruction of chemically stable, carbonaceous species (Salama et al. 1996).

Investigations of DIBs in regions of different metallicity, chemical properties and UV radiation field may allow us to constrain the physico-chemical properties of the (different) DIB carriers.

Unfortunately, it is difficult to probe the interstellar medium along a given line of sight; usually this is a combination of many different clouds with inhomogeneous properties and complex morphologies.

DIFFUSE *CIRCUMSTELLAR* BANDS

Since circumstellar shells are sources of replenishment of the interstellar medium, it seems reasonable to expect that DIB carriers may also be present in some of these shells. In particular, the suspected connection between DIB carriers and some carbon-rich compounds can be investigated attending to the usually known chemistry and physical properties of these circumstellar shells.

A first attempt to detect Diffuse *Circumstellar* Bands was carried out by Le Bertre & Lequeux (1993) using a sample containing a mixture of carbon-, oxygen- and nytrogen-rich mass-losing stars. However, they failed to reach any firm conclusion from the results obtained. In particular, they did not detect any band in the spectra of sources with strong PAH emission at mid-infrared

wavelengths, contrary to their expectations. In contrast, strong DIBs were observed toward other carbon-rich sources, as well as toward most of their oxygen-rich and nytrogen-rich sources in the sample.

Observationally, the detection of Diffuse Bands (DBs, hereafter) around evolved stars is hampered by the fact that most mass-losing stars are usually strongly variable stars, surrounded by very cool extended atmospheres where molecules are the dominant source of opacity. These stars are very difficult to model and DBs are hardly detected against the forest of features attributed to molecular transitions which appear overimposed on the stellar continuum. This has prevented the systematic search for DBs in evolved stars in the past.

TABLE 1. Main characteristics of the Diffuse Bands included in our analysis

DB (Å)	FWHM (Å)	EW/E(B−V) (Å)/mag
5780	2.2	0.46
5797	1.1	0.19
5850	1.1	0.050
6196	0.9	0.053
6284	4.5	1.05
6379	1.1	0.093
6614	1.2	0.21
6993	1.6	0.12
7224	1.3	0.25

POST-AGB STARS AS IDEAL TARGETS FOR DB STUDIES

Fortunately, an alternative exists which have so far not yet been explored. These are the post-AGB stars, rapidly evolving stars in the transition from the Asymptotic Giant Branch (AGB) to the Planetary Nebula (PN) stage. While in the early post-AGB stage, these stars are still surrounded by the relatively thick circumstellar shells formed during the previous mass-losing AGB phase. Their central stars show a wide variety of spectral types ranging from M to B in which seems to be an evolutionary sequence in their way to become PNe. And the chemical composition of the gas and dust in the shell can easily be determined from observations at optical, infrared, mm/submm or radio wavelengths. In addition, they are located in many cases at relatively high galactic latitudes, which favours the potential circumstellar origin of the features observed.

In order to make a systematic study of the presence of these bands in post-AGB stars, we carefully selected a sample of 33 sources displaying all kind of spectral types from G to B[1]. and covering a wide range of galactic latitudes. It contains a mixture of C-rich and O-rich stars with a well determined value of the colour excess E(B−V), as a reddening indicator, .

The sample was then split in two subgroups according to whether the overall extinction observed is predominantly interstellar or circumstellar in origin (see the details of how this classification was done in Luna et al. 2005; in preparation).

High resolution spectra taken at various telescopes covering the spectral range 4000 – 10000 Å (many of them originally taken for chemical abundance analysis purposes at the VLT and kindly provided by Hans van Winckel and collaborators) were used for our analysis.

[1] Stars with spectral types later than G were discarded for the analysis, to facilitate the identification of the features against the stellar continuum.

RESULTS

Up to nine different DBs were investigated in detail. Table 1 lists the wavelengths corresponding to these features; their typical FWHM, as a way to characterize their broadness; and their sensitivity to the reddening, measured as EW/E(B−V), re-derived by us from the analysis of a sample of field stars compiled by Thornburn et al. (2003) for six of these DBs and by Jenniskens & Désert (1994) for three other ones.

Note that to distinguish these weak features from weak stellar lines or telluric contaminations is not always a simple task and makes it necessary to use detailed stellar models (to subtract the atmospheric features) and high resolution spectroscopy (to properly remove undesired contaminations), as the only way to derive the accurate strength of each band.

In Figure 1 we show the results obtained for the 6284 Å feature, which is not only the strongest but also the broadest band included in our analysis and, as such, relatively easy to measure, in spite of the contamination by telluric lines, which must be carefully removed.

As we can see, the strength of the 6284 Å feature in sources dominated by interstellar extinction follows the same trend observed in field stars, supporting that there is a tight correlation between the band strength and interstellar reddening. In contrast, all sources which appear to be dominated by circumstellar extinction, show a DB strength far below the value expected for the observed reddening. In the most extreme cases, we find stars in which the 6284 Å band is not even detected, while they are considerably reddened in the optical.

These results are applicable to all stars in the sample, independent on whether they are C-rich or O-rich, and/or

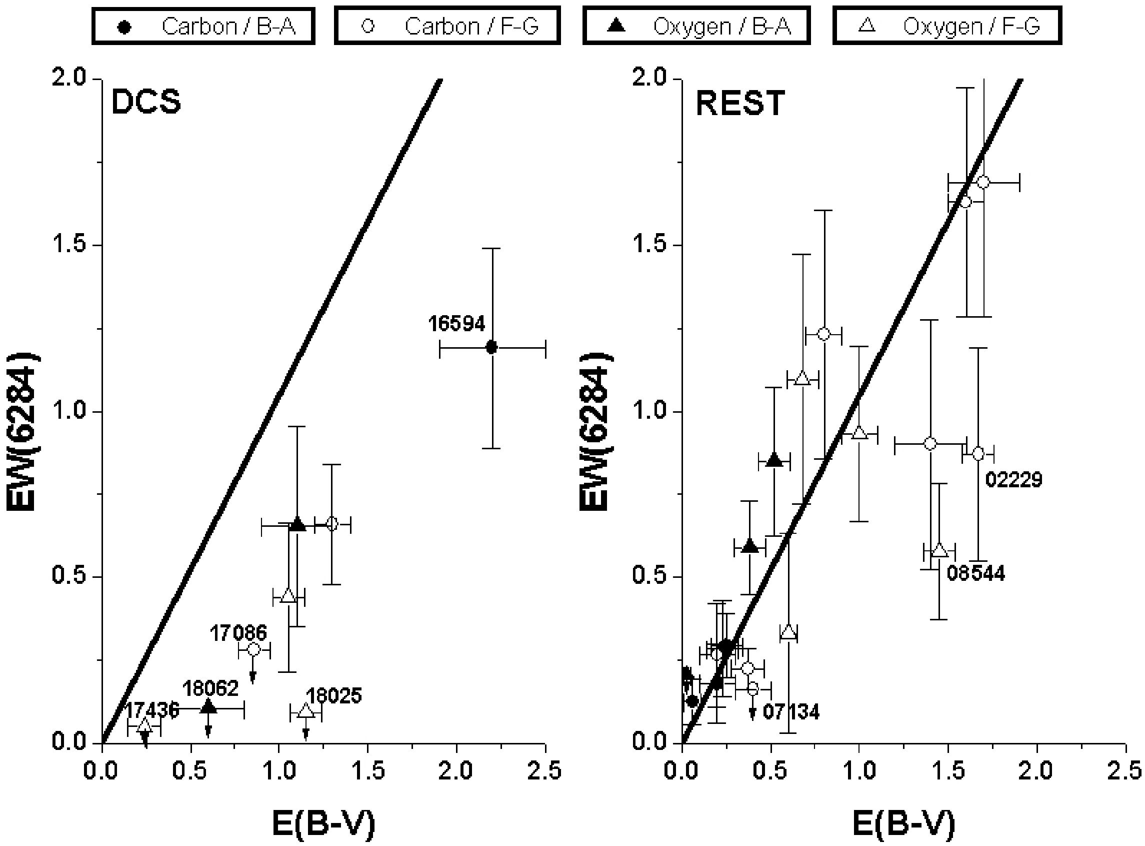

FIGURE 1. Equivalent width of the 6284 Å feature as a function of the total reddening observed in the direction of the sources in our sample. Sources dominated by circumstellar extinction (left) are compared to those for which intestellar extinction seems to be the dominant contributor to the observed reddening. The solid line represents the correlation found in field stars, and is shown for comparison. Different symbols are used for C-rich and O-rich stars and for early-type (B-A) stars and intermediate-late (F-G) type stars.

whether they are early-type stars (B-A) or intermediate-late (F-G) type stars. A few outliers observed in the right panel, like IRAS 02229+6208 or IRAS 08544-4431, with labels in the figure, are also observed as outliers when other DBs are analysed. These stars may have been incorrectly identified as dominated by interstellar extinction.

The same trend is observed when other DBs are investigated. Figure 2 shows the results obtained with the 7224 Å feature, as an example. In general, the strengths of the DBs are found to be well correlated with the interstellar extinction only in those sources showing little circumstellar contribution to the overall reddening, while DBs are weak or absent in sources dominated by circumstellar reddening.

DISCUSSION

Globally considered our results suggest that the carrier(s) of DBs must not be present in the circumstellar shells of post-AGB stars. At least, not under the environmental conditions needed to excite the transitions which we identify as DBs in the interstellar medium.

In particular, we do not find any evidence of the carbonaceous nature of the carrier(s), something generally accepted in the literature, nor any correlation with the presence of PAHs in the mid-infrared spectrum of these sources, as it has been claimed by several authors in the past.

If DBs are connected with PAHs or with any other carbonaceous species such as the ones suggested in the introduction of this paper, their carrier(s) must form at a later stage, under different conditions, when the envelope of the post-AGB star is totally diluted in the interstellar medium as a result of the expansion of the shell, perhaps as a result of their processing by the hard UV photons

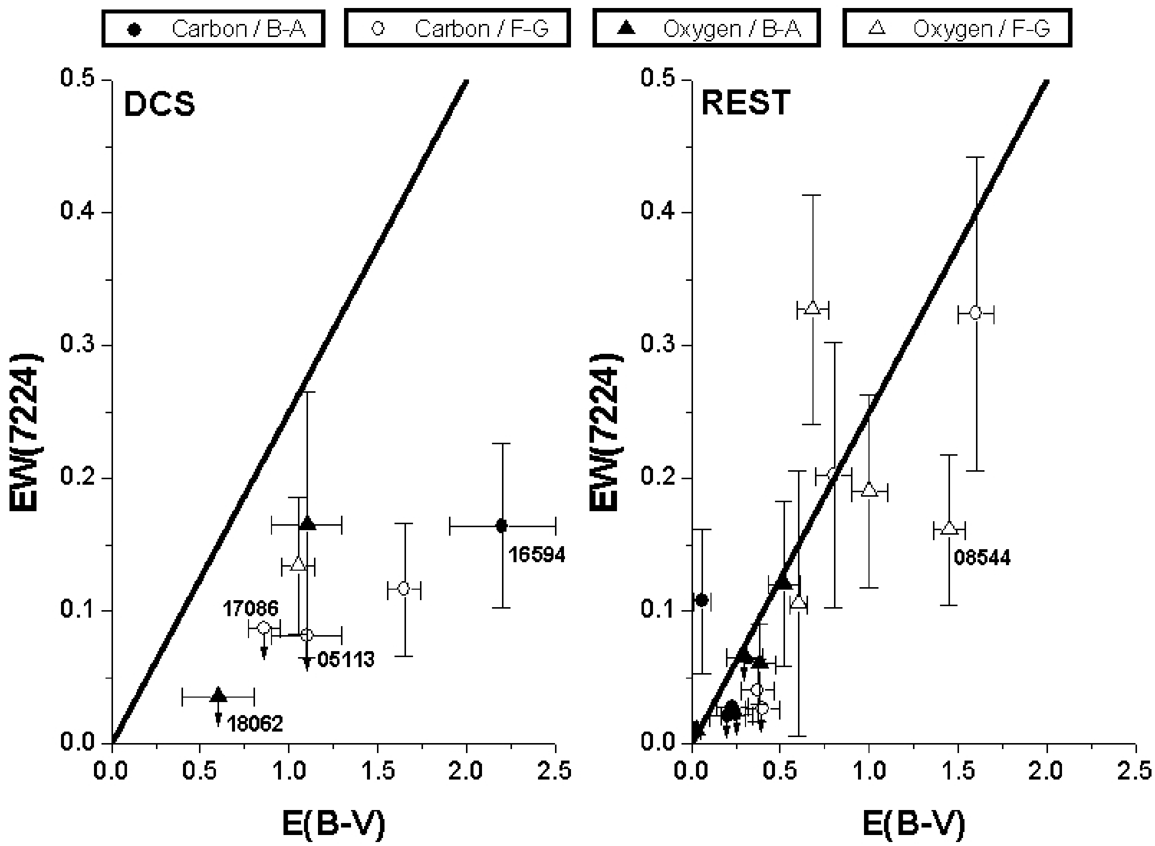

FIGURE 2. Same as Fig. 1, for the 7224 Å feature.

present in the interstellar medium.

In this sense, the identification of the carriers as strongly ionized PAHs and/or radicals liberated from carbonaceous species as a consequence of photoevaporation of dust grains in the interstellar medium would be consistent with our observations.

In order to confirm this hypothesis we plan to extend our analysis in the near future to other sources in a similar evolutionary stage and study in particular very young C-rich PNe in which the UV field may be already strong enough to produce the *in situ* formation of some of these carriers.

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